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Circular No. 707

Saline Soils

Their Nature and Management

By

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THE United States Regional Salinity Laboratory of the Bureau of Plant Industry, Soils, and Agricultural Engineering, at Riverside, Calif., was established on December 23, 1937, under authorization of the Bankhead-Jones Act of June 29, 1935. The special research conducted is in cooperation with the agricultural experiment stations of 11 Western States and Hawaii to attack problems of regional or national scope for maintaining food production on saline soils suitable for cultivation. The results of experiments at the laboratory are made available to the cooperating States and to farmers and farm advisers.

Nearly half the land under irrigation west of the Mississippi River has had its productivity impaired or threatened by an accumulation of soluble salts. Thousands of such acres have been abandoned because of salinity.

For leaching salts from soils by increasing soil permeability and improving drainage, practical methods are being developed, as well as methods for selecting salt-tolerant and other important crops and strains of these crops and for determining cultural practices that will reduce salt accumulations or their effects on plants.

On irrigated lands it has been found that leaching and drainage may be limited by artesian conditions, soil impermeability, or absence of a good water-collecting system, as open ditches, tiles, or a sandy layer for lateral flow to some outlet. Experiments with soil probes and observation wells have shown where drainage is feasible. Observation wells of small-diameter pipe facilitate daily readings of ground-water levels, which, when rising, constitute a danger signal in an irrigated area, for the salt is then accumulating after evaporation more rapidly than it can be removed by drainage. By means of a series of these wells the direction of water movement can be determined, permeable and relatively impermeable layers located, and drainage properly installed.

The purpose of this circular is to present information developed: (1) On feasible drainage for preventing accumulations of alkali salts and facilitating their removal; (2) on the possibility of leaching the salts from the soil or counteracting their effect by soil amendments, direct or in irrigation water; (3) on the wide variation of certain plants in their tolerance to salts; and (4) on the economical possibility of soil reclamation, considering land values.

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UNITED STATES DEPARTMENT OF AGRICULTURE

Saline Soils, Their Nature and Management[1]

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SUMMARY

A LARGE PART of the 20,000,000 acres under irrigation in the 19 Western States contains enough soluble salt to depress crop yields. A much smaller area contains so much alkali that crop production is greatly curtailed and unprofitable. Thousands of acres have been abandoned because of salinity.

On the soils commonly called white alkali, which contain accumulations of neutral salts, as chlorides or sulfates, a soil basis of 0.2 per-

[1] This work was performed under an allotment from the Special Research Fund authorized by Title I of the Bankhead-Jones Act of June 29, 1935.

cent of salt will reduce yields of salt-sensitive plants, and 1.0 percent will cause marked yield reductions in most crops.

On the black alkali soils, in which about 50 percent or more of the adsorbed bases are sodium, a dark residue of dissolved organic matter remains after the surface water has evaporated.

The physical condition of black alkali soils is usually not conducive to plant growth: in addition, the high pH values and soluble substances are at times caustic or corrosive to plants.

Greenhouse tests of the salt concentration in the culture solution indicate that chlorides and sulfate salts have approximately an equal crop-depressing effect. The reduction in yield is proportional to the concentration. In addition, specific effects are caused by the type of ion.

If drainage is poor and the water table is maintained near the surface of the soil, evaporation will be high and salts will accumulate. To prevent such accumulation and to facilitate removal, good drainage is necessary.

White alkali salts can be removed by leaching.

Black alkali soils require soluble calcium in addition to leaching. This calcium may be contained in sufficient quantities in the irrigation water, or as lime or gypsum in the soil, or it may need to be added as a soil amendment.

Plants vary widely in their tolerance to salts. Of the agricultural crops, beets are among the most salt tolerant and beans the least.

Almost any soil can be reclaimed for agricultural use, but, considering land values, in some cases the cost in time and materials may be excessive.

THE FACTOR OF SALINITY ON IRRIGATED LANDS

The value of crops produced on the irrigated lands of the 11 Western States in 1929 was estimated at $824,000,000. A decade later the value had dropped to about $500,000,000, but during the war these values have again risen sharply. Thus in 1943 the value of the single category, fruits and nuts, for California alone, exceeded $500,000,000. Losses in crop production caused by salinity are estimated at $75,000,000 or more annually. On much of the 20,000,000 acres of farm land now irrigated west of the Mississippi the crop yields are reduced 10 to 20 percent by salinity, or an excess of soluble salts in the soil, commonly called alkali. Salinity causes not only a reduction of crop yields but also, if severe, an outright abandonment of irrigated land. During the decade 1929–39, more than 1,000,000 acres were abandoned, and probably half this abandonment may be attributed in large part to salinity. The average value of irrigated land, including improvements on wholly irrigated farms, was estimated by the Federal census to be $67.78 an acre in 1930 and $35.87 in 1940.

Monetary losses, however, are not the only index to losses from salinity. The blasted hopes, social changes, losses in public improvements on areas no longer in production, and removal of lands from the tax roll, making the tax burden that much greater for the remaining lands, are equally compelling reasons for safeguarding the lands now irrigated. Can it be done? Most of those who are con-

versant with the problem answer in the affirmative, recognizing, of course, that the effort will require appreciable expenditures for drainage systems, better water control, and continued research.

Definitions of the technical terms used in this circular will be found in the glossary, on page 27, which, for ready reference, contains also tables of equivalent values.

FORMATION OF SALINE SOILS

In this circular the term "saline soils" is used to denote soils having an accumulation of soluble salts, often called white alkali, and having a pH value below 8.5. Soils containing alkali salts, as sodium carbonate, or considerable sodium combined with the soil minerals, and having a pH value above 8.5 are called alkali soils. These soils often have been called black alkali soils. Correspondingly, the term "salinity" is used with reference to the state or degree of being saline. The process by which these soils are formed is described more fully below.

Origin of Salts

The minerals in a soil are gradually decomposing, some faster than others. Water alone, and particularly water containing carbon dioxide, is an active agent in removing the more soluble parts or elements of a soil mineral in most regions. Usually soil water containing small quantities of dissolved material (salts) disappears by drainage, but where rainfall is low, as in arid regions, the greater proportion of the water will evaporate, leaving these salts to accumulate in the soil. While this process goes on everywhere, there are probably few localities where enough salt has accumulated in place from the weathering of primary rocks to make the soil unproductive from that reason.

Heavy rains almost always occur in the deserts a few times each decade, except in a few places in the world, as in parts of Chile. These rains redissolve the soluble salts on the soil surface and carry them to new locations in the surface runoff. Rain water entering the soil also dissolves salts and transports them in the ground water to streams. In the Great Basin of the United States the temporary streams and rivers end in ponds, sinks, or lakes that may be dry a large part of the time.

Agricultural areas today are sometimes situated over such old salt-deposit areas. In the Imperial Valley of California and in the Pecos River Valley of New Mexico and Texas salt deposits occur in some places at depths of a few feet to hundreds of feet. Occasionally the upward movement of water may traverse these salt beds and rise to the surface, thus bringing salt to the root zone of cultivated plants.

Geologists have shown that much of the western United States was once under the sea. These upraised areas in some places have rock formations containing considerable salt; for example, the Green River formation of Utah and the Mancos shale of Wyoming, Colorado, and Utah. Rain water falling on these shales and seeping through them carries much salt and transports it to adjacent or distant lands at a lower level.

Salt Accumulation

In almost every case salts have accumulated in our present irrigated soils as a result of transportation (*6*)[2]—either by irrigation water, ground water, or uncontrolled surface water—while in a few small areas considerable salt has accumulated in the deposits from which the soil has been formed.

TRANSPORTATION OF SALTS

Water will dissolve about 2,500 parts per million (p. p. m.) of gypsum (calcium sulfate) and about 350,000 p. p. m. of common salt (sodium chloride). A few river waters may be saturated with the slightly soluble gypsum but not with the other salts. In fact, most rivers contain less than 1,000 p. p. m. of total salts. The range in concentration and composition of irrigation waters is described on page 7.

The Colorado River, which is a good illustration of how salt is gathered up by the drainage water throughout the basin and brought into the river, contains about 800 p. p. m. of salt and carries 6,000,000 to 10,000,000 tons of it into Lake Mead annually. This gives an idea of the tremendous quantities that are transported by rivers and that may be carried into an agricultural area by irrigation water and left there as the water evaporates.

Most of the water carrying salt to an agricultural area evaporates. Scofield[3] has shown that on a small area in the Imperial Valley, where an accurate check has been made, only about 6 percent of the quantity applied as irrigation water reappears in the drainage system; the other 94 percent is transpired by the growing plants or is lost by evaporation from the soil surface. In many agricultural areas a still greater fraction of the water evaporates and most of the salts arriving in the irrigation water accumulate in the soil. In some areas salts steadily increase where not leached by drainage.

After a period of accumulation the quantity of salts in the soil may be sufficient to affect plant growth seriously. It usually is considered that salt-sensitive plants will show some growth reduction in soils having a salt content of about 0.2 percent.[4] The surface acre-foot of soil weighs about 4,000,000 pounds; hence 0.2 percent is equal to about 8,000 pounds, or 4 tons to the surface acre-foot. Thus 4 feet in depth of an irrigation water containing 1 ton of salts per acre-foot of water will add enough salt to a soil previously free of salts to make it slightly saline.

If large quantities of salts are present, enough will remain on the surface as the water evaporates to form a thin gray or white crust or deposit. To such deposits and to soils containing appreciable quantities of such salts, the term "white alkali" has been applied, but the term "saline soils" is preferred.

The salts accumulating in a soil may vary greatly in composition. In some areas common salt (sodium chloride) may be the chief salt;

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[2] Italic numbers in parentheses refer to Literature Cited, p. 30.

[3] Unpublished analyses by C. S. Scofield, Division of Irrigation Agriculture, U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering. 1943.

[4] Definition of units and comparison of methods of expressing salt concentration are given on pages 27 to 30.

in others, sodium sulfate, calcium chloride, magnesium chloride or magnesium sulfate, or other salts may predominate or mixtures of salts may occur. Small quantities will not cause any appreciable change in the structure of soils unless they are mainly sodium salts. Larger quantities will improve the structure and increase the permeability of soils to water, unless sodium salts predominate, in which case other reactions occur, which are discussed on page 6.

PHYSICAL NATURE OF SALINE LANDS

If salts are added to a soil, the finer soil particles aggregate and have less tendency to clog the pores. Addition of salt or of irrigation water containing salt at first, therefore, tends to improve the physical condition of the soil, which is shown by increased permeability to water. Often, however, secondary reactions set in and make the soil far worse than it was originally. These secondary processes are described in the following section.

BLACK ALKALI SOILS

The finer soil particles, or soil colloids, act as large insoluble complex anions with which a number of bases are combined. In normal fertile soils these bases are largely calcium, although a small percentage of magnesium, potassium, and sodium also is present. On leaching a soil with a solution containing another base, as sodium, a large part of the calcium combined with the soil colloid will be removed and sodium from the solution will take its place. These bases are therefore said to be exchangeable or replaceable and are commonly called adsorbed bases.

The relative quantities of calcium, magnesium, potassium, and sodium, which are the principal replaceable bases of western soils, combined with the colloid of any soil, are governed by the relative percentages of each of these bases in the soil solution. Some of these bases are more active than others, and a soil solution containing less than 75 percent sodium usually will result in the soil colloids having less than 25 percent. Such a soil colloid is said to be 25 percent saturated with sodium, indicating that sodium occupies 25 percent of the areas where there are chemical bonds that will hold bases.

If the accumulated salts are principally sodium salts, the finer soil particles, or soil colloids, will contain larger quantities of sodium than normal, and this will change their physical properties as well, particularly if most of the salts are removed. The removal of salts by leaching, either in nature or by artificial means, is called desalinization.

A description of the soil changes taking place during this process, according to the most widely accepted theories, is given by Byers and others (*1, pp. 976–977*), as follows:

> When drainage conditions on saline soils are improved and when they are irrigated or receive fresh water from some other source, the salts are gradually dissolved and leached away. As long as there is an abundance of salts in the soil the colloidal clay materials are held more or less aggregated, and the soils are usually sufficiently porous for water to pass through rather readily. So long as sufficient salts remain, this structure is maintained, and the sodium-saturated colloids are not able to hydrolyze. If there is an abundance of

calcium in the soil in the form of soluble salts or as finely divided lime the condition of good percolation is maintained . . . If, on the other hand, the calcium content is low and the sodium content high, the sodium clays will hydrolyze to form free sodium hydroxide as soon as the greater part of the salts has been removed. This results in the deflocculation of the colloidal particles, and the soil becomes sticky, jellylike, and impenetrable to water, thus restraining the further improvement of such soils or actually rendering them unproductive even though the soluble salt content may be below the percentage limit normally toxic. The soil solution becomes very strongly alkaline, and very few plants can survive under these conditions. Accompanying the deflocculation of the clays, organic matter is dispersed and colors the entire soil mass dark brown or black. In this stage the soil is popularly known as black alkali. Some sodium carbonate is formed through the reaction between sodium hydroxide and carbon dioxide of the air.

Following the deflocculation of the clays, there is a tendency for them to migrate downward through the soil and to collect in slightly lower levels, leaving a coarser-textured material at the surface as a very thin coat. The soil in this stage of development is sometimes described as an alkali-claypan type. The clay horizon is extremely heavy and plastic when wet and very hard and columnar or prismatic in structure when dry even though the percentage of clay may not be very high. The columns or prisms tend to become rounded at the top, and the gradual horizontal movement of water over them during wet weather tends to cause the development of a white or light-gray leached silty layer from which organic and mineral colloids have been removed by the water. Among pedologists [soil scientists] these alkali-claypan soils are known as Solonetz, a term which has been adopted directly from the Russian . . .

Many objections have been raised to this theory because a number of Solonetz soils examined have contained a rather high content of absorbed calcium, and in some cases of magnesium. This seems to be in conflict with the theory inasmuch as high calcium content is supposed to prevent the deflocculation of the colloidal material of soils. Some hold the theory that magnesium has an effect similar to that of sodium, so that there might be magnesium Solonetz as well as sodium Solonetz. Others believe that the magnesium ion has an effect similar to that of calcium and should, therefore, tend to keep the soil in a more or less granular condition and prevent deflocculation. Up to the present time no one has satisfactorily proved the theory of the formation of Solonetz . . .

The foregoing quotation describes the mode of formation and properties of soils in which the process of alkalization has progressed to the greatest extent. The acreage of such areas in agricultural production, or considered for that purpose, is small, but there are extensive areas now farmed or considered for reclamation in which the process has proceeded part way.

THE SOIL SOLUTION

Until a few years ago it was believed that plants obtained all their mineral nutrients from the water solution bathing the soil particles in the soil. It is now known that they can obtain part of their mineral nutrients by direct contact with the soil particles, but it has not been determined whether this constitutes an appreciable part of the total requirement. A normal silt loam soil may contain 25 percent moisture after irrigation. This quantity will fill all the smaller pores in the soil, but about half the total pore space will still contain air. Highly soluble salts will be dissolved in this soil moisture, and in addition the less soluble materials will dissolve in the moisture to the limit of their solubility. As moisture is removed from this soil by plant roots or from the soil surface by evaporation, the remaining water still contains most of the salt previously present and the concentration of salt in the soil solution increases.

Numerous methods have been devised to remove the soil solution from a soil for analyses, but such analyses do not tell a great deal about the productivity of the soil, because some soils can maintain a supply of plant nutrients in the solution while others cannot. A recently perfected method makes it possible to obtain the soil solution from soils at low moisture contents, even as low as that occurring when plants can no longer extract the water and in consequence wilt. At this latter soil-moisture content, the concentration of salts in the soil solution will be the greatest that plant roots will encounter in that soil. Analyses of such soil solutions have shown that in fertile soils the concentration at wilting-moisture percentage may reach 2,000 or 3,000 parts of salt per million parts of soil solution.

In soils containing so much salt that plant growth is greatly reduced, the concentration of salts in the soil solution at wilting-moisture percentages may exceed 50,000 p. p. m.

IRRIGATION WATERS

Range in Concentration

Irrigation waters from snow-fed mountain streams contain very little salt, sometimess less than 100 p. p. m. At the other extreme, some irrigation waters contain as much as 10,000 p. p. m. Most of the waters used for irrigation in the United States contain less than 1,000 p. p. m.; thus the Colorado River at Yuma, Ariz., contains 790 p. p. m.; the Rio Grande at Elephant Butte Dam, N. Mex., 640 p. p. m.; and the Snake River at Hagerman, Idaho, 380 p. p. m.

Range in Composition

A few irrigation waters contain mainly one salt; for example, the Salt River, of Arizona. Here a few springs contribute a very large quantity of sodium chloride, thus giving the river its name.

In other regions, as the Grand Junction area of Colorado, where the soils and rocks contain much gypsum, the small streams are often saturated with it. At room temperature, water will dissolve only about 2,500 p. p. m. of this salt, although often soil solutions and at times irrigation waters contain more than this accumulation of calcium and sulfate ions because of the presence of other salts or because the solution is supersaturated.

The principal anion in mountain waters is usually bicarbonate, and the principal cation calcium. As waste irrigation and drainage waters and other streams enter the river, the total salt concentration increases as well as the proportion of sodium, chlorides, and sulfates.

The range in percentage of calcium, magnesium, and sodium to the total cations and of bicarbonates, chlorides, sulfates, and nitrates to the total anions normally present in irrigation waters is approximately as follows:

	Percent		*Percent*
Calcium	10 to 90	Bicarbonates	10 to 70
Magnesium (usually less than calcium)	1 to 40	Chlorides	20 to 80
Sodium	20 to 90	Sulfates	20 to 80
		Nitrates	0 to 5

In waters that have high salt content, sodium is usually the predominant cation and chlorides and sulfates are the predominant anions.

The relative quantities of calcium and sodium absorbed on the soil greatly modify its physical properties and its permeability to water. Magnesium behaves very much like calcium in this respect. Because the quantities of cations absorbed in a soil are governed by the quantities of these cations in the irrigation water or soil solution, the ratio of sodium to calcium plus magnesium in an irrigation water is important. This ratio is commonly designated as the sodium percentage, is defined as the ratio of sodium to the sum of all cations, and is expressed as a percentage.

Typical Analyses of Irrigation Waters

The analyses of selected irrigation waters shown in table 1 bring out the following points.

The Rio Grande at Del Norte, Colo., sample 1, represents a mountain water low in total salts and high in the percentage of bicarbonate. Analyses of sample 2, taken from the same river in southern New Mexico, show the increase in concentration between Colorado and New Mexico and the increasing proportion of sodium, chlorides, and sulfates.

Sample 3, from the Pecos River near Barstow, Tex., is an example of one of the most concentrated waters used for irrigation purposes. It is used on a soil high in gypsum, and fair to good crops of cotton and alfalfa are obtained.

Sample 4, from the Snake River, Idaho, is representative of waters used in the Northwest. They are, as a whole, low in total salt content.

Sample 5, from the Colorado River, Ariz., was selected to show the type of irrigation water used on fairly heavy soil in the Imperial Valley. The water contains 1.1 tons of salt per acre-foot, which is a little more than the average for irrigation water.

Sample 6, from a well used for irrigation, was selected as a water of high sodium percentage. Used on sandy soils, it does some injury to grapes. The boron content is fairly high.

Table 1.—*Analyses of selected waters used for irrigation*

Sample No.	Source	Specific electric conductance ($K \times 10^6$ at 25°C.)	Concentration		Constituents (m. e. per liter)								Sodium	Boron
					Cations (bases)				Anions (acids)					
			Per acre-foot	Total solids	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3		
			Tons	*P. p. m.*									*Pct.*	*P. p. m.*
1	Rio Grande, Colo.[1]	8.5	0.1	81	0.56	0.27	0.30	----	0.70	0.32	0.12	(2)	26	----
2	Rio Grande, N. Mex.[3]	87.0	.8	641	3.76	1.34	4.03	----	2.97	4.69	1.53	----	44	----
3	Pecos River, Tex.[4]	915.0	8.4	6,198	30.62	17.19	53.62	----	----	44.52	54.00	----	52	----
4	Snake River, Idaho[5]	----	.5	380	2.60	1.80	1.74	0.14	3.28	1.69	1.18	0.04	28	----
5	Colorado River, Ariz.[6]	113.5	1.1	795	5.08	2.21	4.54	----	2.56	6.97	2.31	.04	35	0.14
6	Well in Coachella Valley, Calif.[7]	174.0	1.2	910	2.14	.08	12.67	----	1.02	1.80	12.04	.14	85	.71

[1] At Del Norte, Colo. (*24; 25, p. 456*).
[2] Trace.
[3] At Elephant Butte Dam; mean for calendar years 1931–36 (*24; 25, p. 456*).
[4] Near Barstow; Sept. 19, 1940 (*21, p. 291*).
[5] At Hagerman (calculated from data of sample No. 2 (*26, p. 174*)).
[6] At Yuma; average of analyses for 1942 (unpublished data of Bureau of Plant Industry, Soils, and Agricultural Engineering).
[7] Laboratory No. 11429 (unpublished data of Bureau of Plant Industry, Soils, and Agricultural Engineering).

Tentative Standards for Irrigation Waters

Standards for irrigation waters are given at this point, but some of the reasons for their adoption are discussed more fully in succeeding sections (pp. 9 to 18). Plants in saline soils are adversely affected by high concentrations of salts in the soil solution and by poor physical condition of the soil. Both conditions are greatly affected by the type of irrigation water used. An irrigation water having a high sodium percentage will, after a time, give rise to a soil having a large proportion of replaceable sodium in the colloid, often designated as black alkali soil. Even on sandy soils with good drainage, waters of 85 percent sodium or higher will give rise to impermeable soils after prolonged use. With higher total salt content there is a flocculating action that tends to counterbalance the poor physical condition caused by a high sodium concentration in the water. On a heavy soil already high in replaceable sodium, the poorest water that one could use would be one low in total salts but having a high sodium percentage.

The concentration of the soil solution also modifies plant growth and is usually 2 to 100 times that of the irrigation water used, and seldom more dilute. In

heavily irrigated sandy soils the soil solution will tend to approach the same concentration as that of the irrigation water. On heavy soils, where evaporation may greatly exceed drainage losses, the concentration of the soil solution may be 100 times that of the irrigation water and become too great for plant growth.

It is recognized that few farmers can modify their irrigation water, but the table of standards (table 2) given below is to help them appraise what they have or to assist them in evaluating supplies.

TABLE 2.—*Standards for irrigation waters*

Water class	Conductance ($K \times 10^5$ at 25° C.)	Salt content		Sodium	Boron
		Total	Per acre-foot		
		P. p. m.	*Tons*	*Percent*	*P. p. m.*
Class 1 [1]	100	700	1	60	0. 5
Class 2 [2]	100–300	700–2, 000	1–3	60–75	. 5–2. 0
Class 3 [3]	300	2, 000	3	75	2 0

[1] Excellent to good, suitable for most plants under most conditions.

[2] Good to injurious, probably harmful to the more sensitive crops.

[3] Injurious to unsatisfactory, probably harmful to most crops and unsatisfactory for all but the most tolerant. If a water falls in class 3 on any basis, i.e., conductance, salt content, percentage of sodium, or boron content, it should be classed as unsuitable under most conditions. Should the salts present be largely sulfates, the values for salt content in each class can be raised 50 percent. Some of the units here used are defined in the glossary.

Earlier writers, Scofield (*23*), Eaton (*3, 5*), Kelley, Brown, and Liebig (*15*), have usually indicated that waters of 70 percent sodium are unsuitable under most conditions, and a few (*3, 15*) have suggested an even lower upper limit. Yet on sandy soils in the Coachella Valley, Calif., waters of more than 80 percent sodium are used and the farmers stay in business. For class 3 waters a sodium percentage of 75 has therefore been selected. A number of writers, Scofield (*23*) and Wilcox and Magistad,[5] have selected a specific electrical conductance ($K \times 10^5$) of 300 as being the upper limit for good production on most soils and waters. A marked exception occurs in the Pecos Valley, where good growth of alfalfa and cotton was found on lands irrigated with water of sample No. 3 of table 1, having a conductance of 915. The Pecos Valley may be considered a special problem, because of the heavy soil content of gypsum and lime. For this reason the conductance limit for waters in class 3 has been set at 300.

The boron content of a water is of great importance for many crops. Some crops, as beans, are very sensitive to an excess of boron, and others, as sugar beets, will tolerate large quantities. A water containing more than 2.0 p. p. m. will in time usually cause trouble with many of the crops grown.

RECOGNIZING AND DELIMITING SALINE LANDS

In selecting land for an irrigation enterprise, in evaluating land for tax purposes, or for the growth of certain needed crops, and in classifying land for the farmer who is puzzled by poor growth on certain areas, it is highly desirable to be able to recognize saline lands and map their extent. Soils that are covered with a crust of salt half an inch or more thick are obviously so salty that they need be given no further consideration. Soils that contain some salt, but not enough to preclude all vegetation, are of more importance agriculturally and their mapping is more difficult.

PLANTS AS INDICATORS OF SALINITY

In the Western States, where saline conditions are prevalent but may occur in scattered areas not directly related to climatic factors, the type of the native

[5] WILCOX, L. V., and MAGISTAD, O. C. INTERPRETATION OF ANALYSES OF IRRIGATION WATERS AND THE RELATIVE TOLERANCE OF CROP PLANTS. U. S. Bur. Plant Indus., Soils, and Agr. Engin., 8 pp. 1943. [Processed.]

vegetation may give a valuable clue as to the characteristics of the soil with respect to salinity.

The indicator value of native plants depends upon the fact that they must be adapted to their surroundings, for otherwise they could not survive, and thus they serve as measures of their environment. Since early times, man has used the plant cover to guide him in land selection and use. The chief limiting factor in the use of plants as indicators is the lack of complete knowledge of their growth requirements as compared with those of the economic crops that might be selected for a given area.

Sagebrush is a poor climatic indicator owing to its wide range, but it is a good soil indicator. In general, where it grows well, the soil is nonsaline, pervious to a depth of several feet, and its presence indicates that a region is suitable for dry farming or irrigation agriculture. When any of the following species grow abundantly and generally occupy an area, the salinity is usually so high that cultivated crops cannot be grown there unless the soil is thoroughly drained and leached.

Allenrolfea occidentalis (S. Wats.) Kuntze----------Iodinebush.
Atriplex confertifolia (Torr. and Frem.) S. Wats------Shadscale.
A. lentiformis (Torr.) S. Wats----------Saltbush.
Distichlis stricta (Torr.) Rydb. and *D. dentata* Rydb----Saltgrass.
Salicornia europaea L----------Glasswort.
Sarcobatus vermiculatus (Hook.) Torr----------Greasewood.
Suaeda spp----------Seepweed.

Greasewood usually indicates a subsoil that is well supplied with water, has a relatively high water table, and that may contain 0.5 percent salt. Shadscale indicates salt in the first 2 feet, with the soil commonly heavy and containing as much as 1.0 percent salt. This is also true of saltgrass areas, which are undesirable for crop production unless drained but may provide good grazing. Salt flats are frequently characterized by the inkweed and glasswort, with salts approximating 1.0 percent. The seepweed, or saltwort, indicates a high water table and a salt content that may exceed 2.5 percent.

A large number of the salt-tolerant plants belong in the chenopod family, and there is a general uniformity of this type of vegetation in saline areas in arid and semiarid regions. For this reason, land occupied extensively by members of this family, especially species of saltbush and greasewood, would be regarded as potentially saline (pl. 1, *A*). Where use of such land for crop production is contemplated, the soil should be analyzed for salt content and water relations to determine the degree of salinity and the measures needed for adequate reclamation.

Soil Survey Methods

The Division of Soil Survey of this Bureau used a portable Wheatstone bridge for testing and mapping saline soils as early as 1896. In using this instrument a small quantity of soil is moistened and placed in a hard rubber cup between two electrodes. The resistance to passage of an electric current through the soil is measured and serves as an index of the quantity of salt present. This rapid method has been of great value in mapping saline soils. Usually the surveys indicate on the map the quantity of salt, in percentages of the surface and subsoils separately.

The Wheatstone bridge (*22*) gives an approximation of the quantity of salts present because it measures one property of a salt—its ability to carry electric current. The percentage of salt that can produce the same conductance may vary several fold with different salts. Rather than report percentages of salt, which are converted from resistance readings, it has been suggested that the conductance readings be used directly.

There is evidence that some soil minerals conduct electricity and that the conductance of a soil is dependent on the ratio of soil-particle volume to pore space and water content, giving rise to large errors in salt concentration of some cases. Chemical analysis is the most accurate method of determining the salt content of a soil and the concentration of salt in the soil solution. Less accurate than chemical analyses, but more accurate than Wheatstone bridge readings on a moist soil, are conductivity measurements of a soil solution or soil extract.

RELATION OF CROP GROWTH TO SALINITY

General Relations

One method of studying the reaction of plants to high salt concentration is to grow them in solutions or sand cultures to which known quantities of salts are added. The culture containing only plant foods (nutrient salts) in reasonable quantity serves as a control with which plant growth in the other cultures with added salts is compared. This type of study has been used at the Salinity Laboratory since 1939, and by this method it has been possible to make tests and draw conclusions on the relation to plant growth of saline conditions in the soil and in irrigation waters.

A number of experiments have demonstrated that plants absorb less water from saline than from salt-free solutions. This finding agrees with physical laws by which one can calculate the added energy involved in removing water from saline solution compared with removal from a supply of distilled water. Plants growing in saline environments are therefore subject to physiological drought, the magnitude of which will vary with the concentration of salt present. It should not be inferred that this is the only way in which saline soils affect plants, neither can it be dismissed as being of minor importance.

Seed Germination

During the process of germination the embryo uses stored food within the seed, and to carry on the growth processes it needs both water and oxygen. The rate of water absorption by seeds is dependent in part on its salt content. A small quantity of salt assists in the process with some seeds, but large concentrations increase the osmotic value of the solution and reduce the rate of water intake and of germination. According to one author (*9, p. 46*), the following concentrations of sodium chloride in solution are injurious to the seed or young seedlings: Hemp, 2,500 p. p. m.; clover, 5,000 p. p. m.; wheat, rye, beans, and peas, 5,000 p. p. m.

Effect of Salt Concentration

As a result of experiments conducted during the decade 1933–43 it has been clearly shown that there is no threshold where a concentration of salts suddenly becomes toxic and precludes plant growth. On the other hand, Eaton (*4*) and Magistad and others (*18*) have shown that the extent of reduction in growth is related to the quantity of salt present. When dealing with a single salt, any unit of concentration may be used, but when dealing with several salts and comparing results obtained with one salt with those obtained with others, it is desirable to use a concentration unit that will minimize differences in the nature of the salt. Such a unit is that of osmotic concentration, measured in units of atmospheres. More precise definitions and conversions to other units are given in the glossary.

To illustrate the relation between plant growth and salt concentration, results obtained by Gauch and Magistad (7) with alfalfa grown in sand culture to which increasing quantities of sodium chloride were added are shown as table 3. From the data it is clear that increasing salt reduces alfalfa yield at the rate of about 10 percent for each increase of 1 atmosphere of concentration.

Bicarbonates are present in most irrigation waters and soil solutions, and, as previously mentioned, this anion usually predominates in mountain water. (See data on water sample No. 1, table 1.) The quantity of bicarbonate ion that can remain in a solution depends on the quantity of carbon dioxide present, the pH value, the atmospheric pressure, and temperature. Thus the carbonate and bicarbonate situations in soils are dependent on a number of other factors and the experimental controls that determine their effects on plants are involved. A few experiments in which iron and manganese were made available to the plants, so as not to be interfering factors, indicated that bicarbonates by themselves had a low toxicity.

Nitrates are plant nutrients, but are toxic to plants when present in excessive quantity. Irrigation waters usually contain very small concentrations, although

some well waters contain as much as 30 p. p. m. Nitrates accumulate in soils mainly as a product of decomposition of the proteins in organic matter. The soil solution of fertile soils may contain 100 p. p. m. of nitrates, and in a few instances as much as 5,000 p. p. m. have been found. Greenhouse experiments have shown that a high concentration of nitrates reduces plant growth comparable with equal concentrations of chlorides and sulfates. In most cases, however, the nitrate is not present in excessive quantity and is beneficial as a plant food. Where soils already contain a large store of nitrates, addition of more nitrate as fertilizer may be harmful.

TABLE 3.—*Growth of alfalfa with increasing concentrations of sodium chloride*

Concentration of salt (atmospheres)	Yield of alfalfa	
	Per pot	Relative yield
	Grams	*Percent*
0.5 (control)	61.1	100
2.5	45.4	74
3.5	38.9	64
4.5	32.8	54

NATURE OF SALT AND ITS EFFECT ON PLANT GROWTH

At concentrations less than 2 or 3 atmospheres the nature of the salt and ratio of one ion to another in the soil or culture solution may affect plant growth more than does the total concentration in atmospheres. Chlorides and sulfates usually occur in larger quantities in saline soils than do other anions. Tests have been made with chlorides and sulfates at equal osmotic concentrations on a number of plants. With some plants—beans, carrots, and garden beets—the two ions were found to be about equally injurious, although in some cases chlorides were somewhat more toxic than sulfates. Thus Hayward and Long (*10*) report that peach trees died at a concentration of 3.2 atmospheres of chloride salts, while other trees survived in solutions of 3.6 atmospheres of sulfate salts. Soil solutions that contain more than a few parts per million of sodium carbonate are unable to support good plant growth. The plants become spindly and yellow and soon die. It is believed that the carbonate itself is toxic, but always associated with it are high pH values, lack of soluble iron, poor soil structure, and the possible lack of aeration. To separate the effects of these different factors on plant growth is difficult.

Bases found in saline soils are principally calcium, sodium, and magnesium. In rare instances soluble and exchangeable potassium may be present in appreciable quantity, especially where salts have accumulated from ashes or burned areas. Calcium and magnesium are plant nutrients, but in saline soils they always exceed the plant-food requirements. Because sodium is so frequently present in large quantities in saline soils, the belief has arisen that this base may directly produce harmful effects on plants. A few experiments conducted in sand cultures in which the ratios of these bases varied widely indicated that when compared at an equal osmotic basis at higher concentration, calcium, magnesium, and sodium were approximately equal in their action. With most crops calcium was least injurious and magnesium often caused the greatest injury. In soils, of course, the result is somewhat different, as sodium causes the soil to be more sticky and less permeable to water and therefore is a poorer environment in which to grow plants. It would appear that in concentrations exceeding 3 or more atmospheres, the effect of any ion on plant growth is mainly proportional to the extent to which this ion has contributed to the total osmotic concentration.

EFFECT OF CLIMATE ON PLANT RESPONSES TO SALINITY

It has been shown that soluble salts increase the osmotic concentration of the nutrient or soil solution and that plants take up less water from solutions of high osmotic concentration. In warm or hot climates, plants transpire more water than in cool climates, and for this reason an equal concentration of salts

might be expected to be more harmful to plants in hot than in cool climates. In studies made to test this point, most of the crops grown in sand culture, including milo, cotton, alfalfa, barley, tomatoes, onions, navy beans, garden beets, and carrots, were injured to a greater extent by the same quantity of salt at Indio, Calif., where the average maximum July temperature was 112° F., than at Torrey Pines, Calif., where the average maximum July temperature was 71°. In the case of a few crops, as alfalfa, climate had little effect on the salt action. Saline accumulations are most prevalent in the warmer regions.

Quality of Plant Products as Affected By Salinity

Very little is known concerning the quality of plants with respect to their growth under saline conditions. Alfalfa grown under such conditions is commonly considered less palatable than that grown on normal soils, but this has not been definitely shown.

When peaches grown in sand cultures with varying degrees of salinity were sampled for quality, it was found that at low salt concentrations the quality is normal, but that at high concentrations the fruit is somewhat less palatable.

Sugarcane grown on salty areas in Hawaii yields a milling juice of higher salt content than normal. In the sugar-making process it is harder to crystallize sugar from such solutions and the remaining molasses contains more salt and has a greater physic action when fed to cattle than molasses from cane grown on normal soils.

Small percentages of chloride in the nutrient solution seem to improve the taste of tomatoes. Plants grown in nutrient solutions having relatively large quantities of calcium or potassium reflect this in the greater accumulation of these ions in the fruits.

Plant Symptoms of Salt Injury

In general, plants show few characteristic symptoms of salt injury unless the concentration is exceptionally high. Those grown in saline soils and sand cultures supplied with saline solutions are smaller than those grown under normal conditions, but if control plants are not available for comparison the dwarf effect is not apparent.

In saline cultures, beans have been observed to tilt their leaves so that the sun strikes them on the edge rather than on the flat surface. This reduces water transpiration from the leaves. Beans exhibit the same phenomenon when growing in dry soils the moisture content of which is nearing the wilting percentage.

On peaches, definite symptoms of leaf injury were observed at high chloride concentrations. The leaves were chlorotic, showing marginal and tip burning, and fell off readily. Small branches showed some dieback on both the high chloride and high sulfate treatments.

TOLERANCE AND SUITABILITY OF PARTICULAR CROPS TO SALINE CONDITIONS

Data on salt tolerance of particular crops to salinity have come largely from field observations, with occasional determinations by means of the Wheatstone bridge of the accumulation of salt present. As already shown, the extent of growth reduction is roughly proportional to the osmotic concentration of the soil solution, and, in the case of field observations, where no salt-free spots are known to exist as reference areas, only general ideas are obtained of the reduction in any particular saline environment. Nevertheless, frequent field observations on many soil types are probably more reliable for general conceptions of tolerance than isolated greenhouse tests. Another difficulty is that in most cases the nature of the salt present in the field has not been determined. Since some salts are twice as toxic as others, on a weight basis, the older observations in which mixtures of salts were reported on a percentage basis are not so accurate as they now could be made in the light of more recent work.

In saline areas, the water table is usually high, and often a crop is needed that is tolerant to both salt and waterlogged conditions. These two requirements are not necessarily met by the same crop.

In a number of tolerance experiments run at the Salinity Laboratory, the growth of plants was compared at known levels of salt concentration. Both

chlorides and sulfates were used, and in a few cases nitrates. The data obtained were combined with those of Kearney and Scofield (*12*) in arranging the accompanying list in the order of increasing salt tolerance. Tolerance to soluble carbonates was not considered, as these salts are highly toxic and often absent.

Relative tolerance of crop plants to salt constituents in the soil solution, arranged in order of increasing tolerance

Weak:
- Peaches, Early Elberta on Lovell rootstock.
- Beans, wax.
- Beans, navy.
- Red clover.
- Field peas.
- Horsebean.
- Vetch.
- Proso.
- Oats (grain crop).
- Emmer (grain crop).
- Wheat (grain crop).

Medium:
- Onions.
- Squash.
- Carrots.
- Ladino clover.
- Sunflower.[1]
- Rice.
- Rye (grain crop).
- Barley (grain crop).[1]
- Oats (hay crop).
- Wheat (hay crop).
- Grain sorghums.
- Foxtail millet.
- Strawberry clover.

Medium—Continued:
- Asparagus.
- Cowpeas.
- Flax.
- Sweetclover.

Medium strong:
- Barley (hay crop).
- Tomatoes.[1]
- Cotton.[1]
- Alfalfa.
- Sorgo.
- Kale.
- Rape.
- Meadow fescue.
- Italian ryegrass.
- Crested wheatgrass.
- Slender wheatgrass.

Strong:
- Tall oatgrass.
- Smooth bromegrass.
- Western wheatgrass.
- Bermuda grass.
- Rhodes grass.
- Sugar beets.
- Milo.
- Garden beets.

[1] Sensitive to boron excess.

Where more than about 20 p. p. m. of soluble carbonates are present, few crops will grow, as this salt seems to have a corrosive action on the plant. Soils containing soluble carbonates are rarely profitable without using some reclamation measures.

Legume Forage Crops

Legume forage crops have filled a vital need on irrigated farms. The farmer has needed more protein for his farm animals than he could obtain from grain crops. Purchase of protein was prohibitive, and to grow grass crops of high protein content considerable nitrogen in the soil was needed. Chemical nitrogen for fertilizer use costs too much, and only by using legumes to enrich the soil for other crops and to furnish high protein forage crops immediately could the average farmer succeed.

Alfalfa was grown on 3,652,000 acres of irrigated land in 1940 in the Western States, or on 17 percent of all the irrigated land. In the seedling stage it is said to be rather sensitive to salt. In some saline areas the practice has been to irrigate the field heavily just after seeding, to drive the salt downward. Preirrigation is also practiced, and in some localities germination is obtained during the rainy season. By the time the salt again accumulates at the surface the alfalfa will have established a good root system.

Various observers, Kearney and Scofield (*12*) and Harris (*9*), have stated that alfalfa will grow well in soil containing up to 4,000 p. p. m. of white alkali, but will tolerate only a little sodium carbonate.

In the test described on page 12 the yield of alfalfa decreased with increasing salinity, and no particular toxic limit can be given. In this test observations indicated that the proportion of leaves to stems decreased with increasing

A, A saltbush association, showing an example of extreme saline conditions as indicated by salt-incrusted soil (mostly sulfate salts); *B*, excessive soil salinity prevents barley growth.

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A, Punjab flax fails to grow on saline spots at Meloland Station, Imperial Valley, Calif. *B*, Field of cotton on sandy loam soil with inadequate subsoil drainage and excessive salinity. Location 54, Barstow area (*21, p. 290*).

salinity, but no data on this point were obtained. The relatively high resistance of old alfalfa to salinity has been ascribed to the fact that feeding roots are in a deep zone, where the salt content is less than that at the surface.

Sweetclover is widely recommended for saline lands, both because of its tolerance to salt and its ability to grow in waterlogged soils. It needs to be seeded every other year. It is easier to get a stand of sweetclover than alfalfa on saline land, and for this reason it is recommended as the crop first to be seeded on land during reclamation. It forms an excellent green-manure crop, but it is not very desirable for hay, as the growth is apt to be rank and woody.

Ladino clover is receiving increasing attention as a forage crop. In a test at the Salinity Laboratory at 4.5 atmospheres ladino clover yielded 42.7 grams compared with 32.8 grams for alfalfa. In this short-time test it outyielded alfalfa at all concentrations and in the control. It is now widely grown on an increasing acreage on saline irrigated lands in California. Ladino clover is a shallow-rooted crop compared with alfalfa, and for this reason requires more frequent irrigation.

Strawberry clover has received considerable publicity as a good legume to grow on saline lands. In a test at the Salinity Laboratory it was no more tolerant to salt than alfalfa and ladino clover, and the yields were far less. It may be particularly adapted to wet or waterlogged conditions. No test of this faculty was made.

Berseem, or Egyptian clover, is grown extensively on saline lands in the Nile Valley, Egypt, and is popular because it grows well on flooded land. It is said to endure 6,000 p. p. m. of sodium chloride in the soil. This legume requires a mild winter and has not found favor in the United States.

Forage Grasses

As a group the forage grasses are tolerant to salts, and some members of the family are among the most resistant of any crop.

Rhodes grass is particularly adapted to warmer regions. It grows well under irrigation, and Kearney and Scofield (*12*) cite it as being among the most salt-tolerant of the grasses. They add that in salt areas it may take up so much salt as to cause scours in livestock.

Bermuda grass is the most important forage grass of the Southern States. It survives submergence and is often recommended for areas under reclamation. Where special precautions are not taken, most lawns in the South are of Bermuda grass.

Western wheatgrass grows well on moist saline soil in the Northern States. Records from Montana indicate that it has shown good growth in the presence of very large quantities of salt.

Smooth bromegrass spreads by underground rhizomes. It is tolerant to salts but does not do well on wet land. In warmer regions other grasses are preferable.

Tall oatgrass was introduced from Europe and is grown in the Northwestern States. It has been found growing in the presence of 7,000 parts of salt per million.

Also recommended are slender wheatgrass, crested wheatgrass, Italian ryegrass, and meadow fescue as being tolerant to rather large quantities of salt.

Cereals

The cereals are moderately tolerant to salts.

Rye has been grown successfully on land containing as much as 17,000 p. p. m. of sodium sulfate and is one of the most salt-tolerant cereals. It is said to give a better stand if the seedbed does not contain more than 5,000 p. p. m. of salt.

Wheat has been grown where alfalfa fails to get started, but under such conditions grain production may be poor. Some investigators (*8, 27*) have indicated that it will grow in soils containing up to 10,000 p. p. m. of mixed salts.

Barley is less tolerant to salts than wheat, according to observers (*11*, *27*). In the warmer climates it is often grown to take the place of corn. At 4.0 atmospheres of salt in sand cultures, top growth was 54 percent of that obtained at 0.5 of an atmosphere. Surface soil to a depth of 4 inches from the bare spot shown in plate 1, *B*, contained 3.6 percent salt. The salt solution at a moisture content near wilting had a concentration of about 50 atmospheres.

Oats are less tolerant than wheat, but can be grown for hay in soils of medium salinity.

Rice is grown on saline lands during reclamation, mainly because it will grow well in water. In Louisiana and Texas it is regarded as sensitive to brackish water.

Corn is sensitive to salinity, according to Harris (*9*), and has been found to fail on even slightly saline soils.

Fiber Crops

Cotton is markedly salt-tolerant, ranking next to alfalfa in relative top growth in sand cultures containing 4.0 atmospheres of salt. It is extensively grown on saline soils in the Rio Grande, Salt River, and San Joaquin River Valleys. Field observations have shown that the long staple, or the Egyptian type, is more salt-tolerant than the upland type of cotton. In preliminary experiments at the Salinity Laboratory some strains set three times as many bolls as others at salt concentrations of 4.0 atmospheres.

Flax is extensively grown on irrigated land in the Imperial and San Joaquin Valleys of California and in Oregon. Hayward and Spurr (*11*) found it only moderately tolerant to salts (pl. 2, *A*). In field as well as in greenhouse tests, length of straw and yiel of flaxseed are closely correlated with salt content. The surface 4 inches of soil from bare spots shown in plate 2, *A*, contained 1.2 percent total salts on a soil basis, while 16-inch flax grew on soil containing 0.1 percent total salts.

Root Crops

Sugar beets belong to the same botanical family as greasewood, saltbush, and glasswort. As would be expected from botanical relationship, they are highly tolerant to salt concentration. Difficulty is often experienced in obtaining a stand on saline soils, but, once established, this plant, by its deep-rooting habit, makes possible relatively satisfactory yields despite high salt concentration. In controlled cultures at the Salinity Laboratory, yields obtained at 4.0 atmospheres of salt were 70 percent of those at 0.5 of an atmosphere. In these small-scale tests there were no appreciable differences in sucrose percentages of plants grown under a considerable range of salt concentration. Quality of the sugar beets for processing, however, tends to be reduced as salt concentration in the soil increases, the effect of increased salt in the beet being to decrease the yield of crystallized sugar. If high nitrates are present, in addition to other salts in the field, sucrose percentages are definitely reduced.

Mangels are close relatives of the sugar beet and are salt-tolerant. They are not widely grown in the United States.

Potatoes are an important crop in irrigated areas in Idaho, California, and Colorado. Usually they are grown in areas where water is plentiful and of very low salt content. They are said to be very sensitive to saline soils—fewer tubers are formed, and these are watery and keep poorly.

Other Field Crops

Beans, both navy and wax, are among the crops most sensitive to salinity. At the Salinity Laboratory pod yields obtained at a salt concentration of 4.0 atmospheres were only about 10 percent of normal. In one test where beans grown on saline soils were replanted, germination of the second generation was markedly reduced.

Field peas are grown to an increasing extent on irrigated lands in the West. They are listed as tolerating only weak salinity—less than 0.4 percent.

Milo is one of the most salt-tolerant crops tested at the Salinity Laboratory. At a concentration of 4.0 atmospheres the grain yield was 74 percent of that obtained in a 0.5-atmosphere nutrient solution.

Sorghum, like milo, is also highly tolerant to salt. It is said to yield good crops in soils containing 6,000 to 8,000 p. p. m. of white alkali.

Trees and Shrubs

Trees and shrubs sometimes grow in very saline soil, because their deep root system feeds in the less saline subsoil. For this reason field observations on growth are sometimes misinterpreted.

Date palms are believed to be the most salt-resistant of cultivated plants. Harris (*9*) states that they have been known to grow in the presence of 30,000 to 40,000 p. p. m. of salt. Magistad and Reitemeier (*19*) report a fair growth of dates in the Imperial Valley, where the soil solution, at a moisture content very near the wilting percentage, contained 15,000 p. p. m. of salts, or a concentration of 7.0 atmospheres.

Grapes are said to be highly tolerant to salts. This is based on field observations, but was not confirmed by a few exploratory greenhouse tests at the Salinity Laboratory. After it has established a deep root system, this crop is probably one that can grow in soils having a highly saline topsoil.

Apples and pears are sensitive to salinity and will not grow well in soils containing more than 2,000 p. p. m. of salt.

Peaches are very sensitive to salts. A comprehensive experiment by Hayward and Long (*10*) in sand cultures at Riverside, Calif., resulted in death of peach trees at 3.2 atmospheres when obtained from chloride salts. At 3.6 atmospheres from sulfate salts, the trees remained alive but did not grow well and produced little fruit. Peaches grown in the base nutrient sand cultures were of approximately the same quality as those grown commercially, but when grown in saline sand cultures at 3.0 atmospheres or more, they were somewhat bitter. There is some indication that, on peaches at least, the salt effect is cumulative, because trees that survived a concentration of 3.2 atmospheres the first 2 years died the third year.

Citrus fruits.—Among citrus, lemons are the most sensitive to salts. Cuttings or young trees have been able to tolerate 1.8 atmospheres of salt in sand culture. Grapefruit will tolerate the most salt, but probably will not yield well except in soils of weak salinity. Oranges occupy a position between grapefruit and lemons in salt tolerance.

Garden Vegetables and Truck Crops

Table beets are closely related to sugar beets and are the most tolerant crop thus far grown at the Salinity Laboratory. The relative yields of roots are 95 percent at 2.0 atmospheres and 75 percent at 4.0 atmospheres.

Tomatoes have received considerable attention as test plants in controlled salinity trials and are found to occupy a midplace in the tolerance table, being slightly less tolerant than cotton and alfalfa. At 4.0 atmospheres top and fruit growth were about 50 percent of optimum, and fruit yields alone were 57 percent of that obtained without salt. The quality of fruit at these concentrations was not impaired; in fact, some preferred those grown at 4.0 atmospheres of chloride to those grown at 0.5 of an atmosphere.

Carrots are relatively sensitive to salts. Yield of roots at 4.0 atmospheres was 26 percent of optimum.

Squashes were found to be sensitive to salinity, with yields of 24 percent at 4.0 atmospheres.

Onions were still more sensitive to salt than carrots or squashes, with yields of 20 percent at 4.0 atmospheres.

Wax beans were very sensitive to salinity, with pod yields only 9 percent of optimum at concentrations of 4.0 atmospheres.

Asparagus is said to be very salt-tolerant and is grown extensively in the Stockton area, California, on peat soils, many of which have a considerable salt concentration.

RECLAMATION OF SALINE SOILS AND PREVENTION OF SALT ACCUMULATION

The measures used to prevent salt accumulation are in many cases identical with those used to reclaim soils now unproductive (*2*, *13*, *16*), and for this reason the two are discussed together.

Saline salts are unfavorable media for plant growth because: (1) Most plants do not thrive in the presence of appreciable quantities of salt, and (2) the physical conditions often associated with saline and alkali soils are unfavorable to plant growth. To restore saline soils to productivity, soluble salts must be removed by leaching and the physical condition improved. Improvement is accomplished: (1) By changes that occur in the soil during the leaching process, (2) by additions of soil amendments and organic matter, and (3) by the action of plant roots.

Drainage

One of the first steps in reclamation is to provide good drainage. This means the absence of free water within the root zone of the soil. The water table should be at least 4 or 5 feet below the surface.

The removal of excess water from the subsoil can be accomplished by means of a drainage system or by reducing the quantity of water getting into it (pl. 2, *B*). Drainage systems may consist of tile, open drains, or pumped wells. The quantity of water that must be removed to maintain a proper water table varies from 5 percent or less to 50 percent or more of the irrigation water applied. In addition to rainfall during certain seasons, the principal contributions to this underground water are from excessive applications of irrigation water and from seepage losses. Better irrigation practices and lining the canals to reduce seepage may be more effective in lowering the water table than the installation of a drainage system.

In some localities most of the underground water enters the subsoil through the more permeable soils on the higher benchlands. The flow is principally through sand and gravel aquifers that may be at appreciable depths below the surface and cause a waterlogged condition in the lower part of the valley. Often present in the aquifer under appreciable pressure, the water enters the surface soil from below. Flowing wells are an indication of such conditions, but while the pressure is often insufficient to produce them, it will move considerable quantities of water upward into the root zone. Where the surface soils are fairly impermeable to considerable depths, ordinary gravity drainage systems are effective for only a few feet on each side of the drains.

The existence of upward flow conditions can be ascertained by installing small observation wells terminating at different depths and by measuring the water levels in each. If the levels stand progressively higher as the wells increase in depth, upward flow is occurring. Where wells of reasonable capacity can be obtained, pumping from them is the most effective method of drainage under these conditions.

In large areas of Arizona and California, drainage is accomplished by pumping from water-bearing strata, which is particularly advantageous where electric power costs are low and the soil formations are such that wells of high capacity can be developed.

It is often futile for a single farmer to try to drain an area, because: (1) He cannot obtain the necessary outlets, and (2) he cannot lower the water table very much on his own land when it is high on adjacent land. Group action is usually necessary; this can be accomplished through the formation of a drainage district. The first step should be to obtain the advice of the county agricultural agent or some other competent person.

Leaching

In areas where winter rains aggregate 15 inches or more, the precipitation is often adequate to wet soils to a depth of at least 6 feet and to carry beyond the root zone most of the salts accumulated since the last thorough leaching. In such areas the quantity of salt accumulating in one season ordinarily is insufficient to decrease crop yields appreciably, and no other leaching is needed than that provided by nature. In drier areas periodic leaching is necessary to remove the salts that gradually accumulate. Leaching is essential to reclaiming land that has an injurious salt content.

To prevent the accumulation of salts in a soil, more water must be applied than will be lost by evaporation or through plants. This increase in water application may range from 5 to 30 percent or more, depending on the salt content of the water and the type of soil. Few data are available on this subject. The drainage water in any area is probably no more concentrated than the soil solution, and enough water should be supplied to keep concentration of salts in the drainage water from becoming excessive. More water is required when the salt content of the original water is high than when it is low. Some soils may be so heavy and have such slow rates of infiltration that it is difficult to obtain any quantity of drainage water (pl. 3, *A*).

If the soil contains a salt crust it may be advantageous before beginning actual leaching to flood the area and drain off as much surface water as possible. Appreciable quantities of salt can be removed in this way.

If the soil is only moderately saline, crops might be grown while the leaching is being carried on. In this case an excess of water is applied. It is possible to determine what constitutes an excess by watching drainage outlets, by sampling the soil to 6 feet or more, by calculation, or by trial and error—having a knowledge of the water requirement of the crop, the moisture-retaining properties of the soil, and the quantity of water applied. Care must be exercised where crops are being grown, for holding water on the soil too long, especially in hot weather, may cause scalding.

Some crops will withstand flooding better than others and are particularly well suited for growth during leaching operations. These include rice, sweetclover, strawberry clover, western wheatgrass (bluestem), and Bermuda grass. Drying out the soil between leaching periods aids aggregation and develops cracks that increase infiltration. If drying is not carried too far, it probably stimulates

root activity, and this in turn improves the physical condition of the soil.

Where the soil contains so much salt that plants will not grow and is level enough to permit flooding, it is best usually to begin leaching without disturbing the surface by plowing or leveling. Weed growth should be encouraged. Basins can be constructed by building levees along contours. (See basin method of irrigation, pl. 3, *A*.) Water should be impounded and allowed to stand until it percolates into the soil. After the initial leaching sweetclover seed should be broadcast among the weeds and encouraged by frequent irrigation. After reclamation has progressed to the point that a good stand is obtained, the sweetclover should be plowed under and alfalfa planted. Leveling operations can be postponed until the soil is fairly well reclaimed. Often it is desirable to carry on leaching operations in winter, when water and labor are more plentiful and evaporation is at a minimum.

Improving the Physical Condition of the Soil

Removal of soluble salts is not sufficient to restore to productivity soils that contain appreciable concentrations of adsorbed sodium. Here it is necessary to substitute calcium for sodium. The calcium may come from three sources: (1) Irrigation water; (2) soil amendments containing calcium, as gypsum; and (3) calcium containing compounds of the soil, gypsum, or calcium carbonate. If the calcium comes from either (2) or (3) it must first get into solution. Gypsum is directly soluble in water to the extent of about 600 p. p. m. of calcium. Calcium carbonate is only slightly soluble, but in the presence of carbon dioxide from the decomposition of organic matter about 100 p. p. m. of calcium can be put into solution. A more effective means is to convert some of the calcium carbonate to calcium sulfate (gypsum) by the addition of sulfuric acid, or by sulfur, which in time is converted in the soil to sulfuric acid. According to McGeorge (*17*), through this reaction sulfur, by weight, is about five times as effective as gypsum.

Effect of Water Quality

As indicated in the section Tentative Standards for Irrigation Waters (p. 8), water containing a low sodium percentage is preferable for irrigation use and is also desirable for reclamation purposes. Ordinarily the farmer must use the water he has available, but if it is of unsatisfactory quality, he can modify it in some cases by the addition of gypsum or other form of calcium. The gypsum can also be added to the soil, and this is a more common procedure.

A water containing a medium accumulation of salt with a low sodium percentage is more desirable than one having a very low salt content (200 p. p. m. or less). Some soils are many times more permeable to such waters than to water containing no salt.

Salt tends to flocculate the soil particles and to increase permeability. As salts are removed by leaching permeability will decrease. A sodium-saturated soil leached with a water of low salt content will sometimes become almost impermeable, or "freeze" during the leaching process. This condition is caused by the hydrolysis of the sodium clay after the salts are removed and by the formation of sodium hydroxide and sodium carbonate, which results in an increase in pH

values. The soil colloids under these conditions disperse, swell, and become jellylike. Such conditions sometimes can be avoided by using water of higher salt content or by drying out the soil, adding gypsum, and again leaching.

Soil Amendments

Gypsum is widely used as a source of soluble calcium for the reclamation or amelioration of black alkali soils. It need not be used if the water contains considerable calcium or the soil contains gypsum. In some cases where gypsum is not obtainable from local sources sulfur is used. Sulfur, in the form of flowers of sulfur, is oxidized in the soil to sulfuric acid, and this reacts with calcium carbonate to form gypsum, which is somewhat soluble. Gypsum should be broadcast and worked into the soil before leaching. Sulfur should be worked into the soil and given time to oxidize, which may take several months, before leaching.

Waste lime from beet sugar refineries is sometimes used and is believed to be effective because of the content of organic matter and plant nutrients. The calcium added also may be more soluble than the calcium normally present. Other soil amendments sometimes used are aluminum sulfate and ferrous sulfate. These give an acid reaction in the soil and act much as sulfur, but usually they are more expensive than either gypsum or sulfur.

Manure and Organic Matter

Organic matter, including manure, has a beneficial effect upon the union of soil particles into aggregates, and in this way it improves tilth and permeability. In addition, during decomposition the organic matter liberates carbon dioxide, and this dissolves in the soil water and forms carbonic acid, which increases the solubility of the calcium carbonate in the soil. Organic matter also adds plant nutrients and minor elements in an available form. Of especial importance from this standpoint are phosphorus, iron, and zinc. The addition of organic matter to the soil may help prevent some physiological diseases of certain crops and it also serves as a source of energy and food for many soil bacteria. Applied with sulfur it hastens the oxidation of sulfur and thereby speeds up reclamation. The organic matter can be obtained from manure or green-manure crops or from crop residues. Manure is not available normally in quantity, but most farmers can turn under sweetclover, strawberry clover, sesbania, or other green cover crops. Growing crops, especially grasses, are believed to improve soil structure by the action of the roots.

Salt Balance

Soil salinity may be handled by the farmer on an account basis. Salt in the irrigation water is sometimes added at rates as high as 2 tons to 1 acre-foot. It is removed primarily by the drainage water. If the additions exceed the losses, salt is accumulating in the soil. The losses are difficult to measure, but in a few small areas with tile drains this has been done. In general, the conception of a salt balance is beneficial because it so clearly demonstrates the need for drainage. The place of some particular salts or ions in such a balance sheet has not

been determined. For instance, a considerable proportion of the calcium entering a soil in the irrigation water may precipitate as calcium carbonate, which is almost inert so far as salinity is concerned. Some calcium and sulfate is precipitated as calcium sulfate, which is only partly soluble. Actually, a salt that is precipitated is removed almost as effectively as though it disappeared with the drainage water.

Summary of Steps To Be Taken To Reclaim Saline Soils

Among the steps to be taken by the farmer in reclaiming saline soils are the following:

1. Obtain information through the county agricultural agent, drainage district supervisor, or others about—
   - (*a*) Kind or quantity of salts present in the fields.
   - (*b*) Quality of water available.
   - (*c*) Presence of calcium carbonate or gypsum in the soil.
   - (*d*) Availability and costs of soil amendments, particularly gypsum.
   - (*e*) Depth to water table.
   - (*f*) Feasibility of drainage and methods to use.
2. Install drainage works or improve the existing drainage system.
3. Put up levees to impound water for leaching purposes.
4. If black alkali is present or the soil has a high percentage of adsorbed sodium, add amendments, as gypsum or sulfur, which are desirable unless the soil already contains gypsum, or the water contains considerable calcium, or the cost is prohibitive.
5. Add manure or other organic matter, if it is available at a reasonable cost.
6. Keep the surface flooded until several feet of water have passed through the soil. Allow the soil to dry at intervals to encourage plant growth and cause cracking, which will often improve permeability.
7. Obtain a good stand of natural weeds if possible, as these will assist in the reclamation process.

Plate 3, *B*, represents a field in the Carlsbad area of New Mexico on Reeves sandy loam, containing considerable gypsum. It illustrates how crop growth can be improved by reclamation procedure. This field, after about 20 years of cultivation, became salty and was subsequently reclaimed by leaching and drainage. The soil solution still contained considerable salts at the time the photograph was taken, but crop growth was much greater than before reclamation.

CULTURAL PRACTICES ON SALINE SOILS

Many crops will tolerate more salt when fully grown than when in the seedling stage. While fields are lying fallow before planting, salts, through evaporation, tend to become more concentrated in the surface soil. This is especially true where the water table is near the surface and water is being continually supplied to replace that evaporated. This accumulation of salts often makes it difficult to obtain germination, or the plants may be badly injured during the seedling stage. To lessen this difficulty it is often recommended that the land be flooded so as to leach the salt accumulations to lower levels before planting such crops as alfalfa. While the salts will again gradually become more concentrated near the surface, the taproots will have grown down into the soil where the concentration is lower and the moisture more plentiful.

When furrow irrigation is used, evaporation from the ridges tends to concentrate the salts there. Following each irrigation, the salts

A, Flooding land to leach away salts. Note basin method of irrigation. Basin on left had been flooded and drained shortly before being photographed. *B*, Alfalfa on land that became waterlogged and salty was subsequently reclaimed and now is highlly productive. Location 107, Carlsbad area, N. Mex.

A, Irrigating melons, using large furrows. Water is admitted to furrows from a header ditch through 1-inch-square lath-furrow tubes. *B*, Irrigation by furrows on land seeded to truck crops, El Centro, Calif.

tend to migrate from the furrows toward the ridges. The salt concentration in the surface inch or two of soil on the ridges may reach a very high stage, and seeds planted there may fail to germinate or the young plants may fail to grow. To overcome this, crops of lettuce or melons (pl. 4, *A*) are often planted on the sides of the ridges near the water line of the furrows where the salt concentrations are appreciably lower.

In general, the cultivation practice has a direct bearing on the salinity problem. Too often the soil is cultivated when it is too wet, and some puddling and compaction of the soil below the depth of cultivation takes place.

IRRIGATION METHODS AND THEIR RELATION TO SALINITY

The primary purpose of irrigation is to replenish soil moisture in such quantities and at such times that available moisture will always be present in the soil for the growth of crops. Various methods are used to apply water to the land, some of which are adapted to specific conditions only, while others are of more general application. The success of each method is dependent upon many factors, including the size of the irrigating stream. This in turn is affected by the source of water and method of delivery, the crops grown, the characteristics of the soil, topography, cost of the irrigation water, and the salinity status. For example, on some soils certain crops cannot be successfully flooded because this procedure will cause puddling of the soil and formation of a crust. Most crops that are grown in rows are furrow irrigated. Sometimes methods poorly adapted to the specific conditions are used, largely because of custom or because the advantages of other methods are not fully understood.

In the following sections the effectiveness of the various methods of irrigation, including flooding, subirrigation, and sprinkling, is outlined in relation to salinity.

Wild Flooding

Wild flooding includes all methods of flooding where levees are not used to control the direction of flow or to confine the water. This method of irrigation is practiced widely throughout the West on a wide variety of soil types and topography. It requires a minimum of land preparation, but its success is dependent to a large extent upon the ability of the irrigator. It is used primarily for alfalfa, pastures, and small grains, and in certain areas for other crops that permit flooding. Wild flooding could profitably be replaced by one of the controlled flooding methods in many places. The excessive waste often resulting from the careless use of water may be one of the principal causes of a high water table, salt accumulation, and seepage conditions on lower land. Wild flooding is not well adapted to leaching purposes, because keeping water on the surface for any length of time, unconfined by small levees, results in excessive waste.

Wild flooding from field ditches, in general, is wasteful of water because of uneven distribution, excessive deep percolation losses, and

runoff. Other things being equal, one irrigator may use twice as much water as another to cover the same area, and most of the difference will be lost by deep percolation and runoff. This method, therefore, is used principally where water costs are low and the crops grown are of relatively low value. Under these conditions expensive land preparation may not be justified, and in many places the water wasted returns to the streams as return flow farther down the valley and is therefore not entirely lost. In some places, flooding is not practicable because of the deposition of fine silt, which tends to seal the soil and adversely affects the crops grown.

Wild flooding with corrugations is a modified method. At the time of planting the crop, small furrows are made that tend to control the direction of flow and help the irrigator in getting the water to the higher spots. With alfalfa and other permanent crops these corrugations gradually become filled with soil and disappear, but they are effective for several years. In some places corrugations are larger and the water is confined to the furrows, whereas in others no attempt is made to confine the water. The method, therefore, might be classed either as flooding or furrow irrigation, depending upon local practice.

Controlled Flooding

Border strip or border check flooding is gradually replacing wild flooding for alfalfa in many localities. Low broad parallel levees are constructed 20 to 50 feet apart, so that the field is divided into long narrow strips in the direction of the slope of the field. The levees control the direction of flow and make it possible to cover all the field with less expenditure of labor and less waste of water and to obtain a more uniform penetration than is generally possible by wild flooding. Although more effective than wild flooding, because of the better control of water, the border strip method is not well suited to leaching purposes, as the water cannot be impounded, except possibly at the lower end of the strip.

Contour basin, or contour check flooding, as it is frequently called, is better adapted to annual crops and orchards, although it is sometimes used for alfalfa and pastures. For orchards and annuals the levees are constructed each year with a blade or disk ridger. The method requires that the land be originally surveyed to locate the contours, and for orchards these contours are then marked permanently on the trees so that they can be readily followed each time the levees are constructed.

For orchards and most other crops, the contour interval, or difference in elevation between adjacent levees, is usually 0.2 foot. After the contour levees have been constructed, the basins are completed by constructing a few alternate cross levees and ditches up and down the slope, so water can be delivered directly to each basin.

The contour basin method is ideally adapted to leaching and reclamation purposes. The levees need not be very high—6 to 8 inches of settled earth is ample in most cases; the important thing is to keep the ground flooded until an ample quantity of water has passed downward through the soil.

In many places salinity is apparent only in spots in the field that remain barren, and these probably grow larger from year to year. Often these spots can be isolated by surrounding levees. By keeping these spots flooded, they can be leached during the growing season without injury to the adjacent crop.

Rectangular basins are adapted to land that is sufficiently level to construct basins of reasonable size without excessive leveling. They eliminate the necessity of locating contours and have the advantage of being uniform in size, resulting in more uniform application of water. For orchards, on land where the slope is 0.5 foot per 100 or less, rectangular basins are preferable to contour basins, provided they are laid out so that the maximum variation in elevation within each basin is not more than 0.2 foot.

Furrow Irrigation

Furrow irrigation is naturally adapted to row crops and is the only practical method of irrigating certain crops (pl. 4, *B*). When the furrows are of the proper length, fairly uniform applications can be made. Since the natural movement of water is outward and downward from the furrow, there is a tendency toward the concentration of salts in the beds between the furrows. Probably this is not serious in most places, as rainfall and the mixing of the surface soil by plowing prevent the accumulation of salts in toxic concentration. As might be expected, the greatest difficulty is in arid regions with very low rainfall and where the irrigation water contains salt in toxic quantity. It is probable that in many places where furrow irrigation is practiced year after year, occasional leaching during the noncrop season would be very helpful in preventing salt accumulation.

Broad furrows have recently come into use in orchards in southern California. These furrows are about 2 feet wide and have a flat bottom. Separated by only a narrow ridge of earth, they function in principle as miniature border strips. Some of the advantages claimed for them are: (1) Reduction in erosion on the steeper slopes, (2) more rapid penetration because of the larger surface area in contact with the water, and (3) a minimum of salt accumulation in the ridges because the direction of water movement is downward over most of the surface area.

Contour furrows are used for orchards on hillsides or on slopes of more than 3 or 4 percent. The trees are planted on contour grades of 1 to 3 percent, depending upon the soil and the cross slope. The furrows between the tree rows follow approximate contour grades. The irrigation of these steeper slopes generally necessitates a concrete-pipe distribution system and often a lined or sodded waste ditch to take care of runoff. This method of irrigation is very effective in minimizing soil erosion and has made possible the cropping of areas otherwise unsuited to irrigation.

Zigzag and cut-back furrows are sometimes employed in orchards, especially on soils of low permeability. They effectively increase the length of the furrow, thereby decreasing the grade and making it possible to wet a larger part of the soil mass than can be accomplished by straight furrows.

Subirrigation

Subirrigation, as practiced in a few areas, requires special conditions, usually a high water table and a fairly permeable topsoil. Water is distributed in ditches that may be spaced 100 feet or more apart and is allowed to run until the soil is wetted by capillarity. In some places the water table is maintained at constant depth and in others it is allowed to fluctuate. In general, subirrigation involves the control of the water table and its maintenance fairly close to the ground surface. If the soil is underlain by a hardpan or other impermeable layer, only a temporary perched water table may be present, but lateral subbing to any appreciable extent can be obtained only where the soil can be completely saturated, at least temporarily.

Since the direction of water movement within the root zone is principally upward, as water is lost by transpiration and surface evaporation, subirrigation would rapidly concentrate salts in the surface soil were it not for certain offsetting factors. In general, subirrigation can be practiced successfully only when: (1) The water has a relatively low salt content, and (2) the salt concentration that accumulates during the irrigation season is leached away by rainfall or by occasionally flooding the surface. Subirrigation is not a desirable method, but it is practiced in some places because it is very inexpensive. It is especially adapted to potatoes and other crops that withstand a high water table and require a moist soil for best development.

Sprinkling

Sprinkling is relatively expensive as compared with most surface methods, and until recently was confined to orchards, truck crops, and nurseries. The development of portable sprinkler systems has extended the use of sprinkling to sugar beets, beans, peas, and other field crops. Sprinkling provides better control of the water than most any other method and makes it possible to apply smaller quantities. A tendency to apply an inadequate supply of water with sprinklers results in poor penetration. In the Sacramento-San Joaquin Delta area of California sprinkling has come into rather general use and has replaced subirrigation in many instances. It is probable that the better yields reported have resulted from the lower water table, a more desirable moisture distribution in the soil, and a reduction in salt concentration near the surface.

SAMPLING DATA FOR SALINITY ANALYSIS

In a number of the Western States the agricultural experiment stations will analyze for salinity content soil and water samples sent by residents of the State. Since an analysis of water or soil for the common soluble constituents (calcium, magnesium, sodium, carbonates, bicarbonates, chlorides, and sulfates) and for conductivity will ordinarily cost about $20, it is important that each sample be well taken, that it be representative of the area, and that complete information accompany it. Often the county agricultural agent will assist in collecting and describing the samples. In this way the body of information collected will have significance in regional studies.

Soil Sampling

The soil should be sampled to a depth of 4 to 6 feet. Usually the surface soil contains more salt than the subsoil, but sometimes this condition is reversed.

It is suggested that the first 2 inches of soil form one sample, 2 to 12 inches a second, and each succeeding foot a separate sample. Because salt conditions vary so greatly in short distances, it is best to obtain soil for each depth from several holes and mix it to form the final soil sample sent for analysis. A shovel, post-hole digger, auger, or soil-sampling tube can be used for obtaining the samples. Often one part of the field will support a good growth of crops, and it may be advisable to send a sample from that area for comparison. The soil samples should be of quart size and placed in strong paper bags, well labeled with a tag inside the package and one also on the outside. Wet samples should be dried. The following data should be forwarded by letter.

Collector's Description of Soil Sample

Collector's No_____ Lab. No_____ Date_____ Collector_____
Name of owner_____
County_____ Location_____ ¼Sec._____, T_____, R_____
Distance and direction from ¼ corner or landmark_____
Description of soil_____
Size of area affected_____
Depth to water table_____
Source of water used for irrigation_____
Quantity and quality of water_____
Crop(s) grown_____
Condition of present crop_____
Additional information_____

Water Sampling

Many of the streams and irrigation waters have been analyzed (*14*), and as they vary so little from time to time the analyses on file are adequate. Inquiry may be made of the State chemist, State engineer, or agricultural experiment station for such recorded analyses. If none is available a sample may be submitted in a 1-gallon container, which should be thoroughly cleaned and then rinsed several times with the water to be sampled. In sampling a stream, obtain the sample in a swiftly flowing part. The following information should be obtained and submitted with the sample, though it is realized that the collector may not be able to supply all the data in each instance.

Collector's Description of Water Sample

Collector's No_____ Lab. No_____ Date_____ Collector_____
Kind of water (spring, stream, lake, well)_____
Name of owner_____
County_____ Distance and direction from nearest town_____
Location_____ ¼, Sec._____, T_____, R_____. U. S. G. S. sheet_____
Distance and direction from ¼ corner or landmark_____
Other description_____
Depth_____ Depth to upper perforations_____ Casing diameter_____
Discharge (c.f.s., g.p.m., in.)_____ Static level_____ Draws down to_____
Temperature (° C. or ° F.)_____ Odor_____ Gas_____ Color_____
Use (irrigation, municipal, industrial, stock, domestic)_____
Approximate acreage served and kind of crops_____
Condition or symptoms of land or crops_____
Owner's opinion of water quality_____
Collector's remarks_____

GLOSSARY

Following are explanations of a number of the terms used in this circular, particularly those related to salt concentration, together with some tables of equivalent value for handy reference.

Adsorbed base.—A cation held on the surface of a soil colloid and removable by leaching with a salt solution containing another cation. Synonymous with exchangeable base and replaceable base. (See cation.)

Alkali soil.—A soil that contains alkali salts, usually sodium carbonate, and has a pH value of 8.5 or higher. The term is frequently used to include both saline (white alkali) and alkali (black alkali) soils.

Alkalization.—A process by which the content of alkali salts in a soil is increased. (See alkali soil.)

Anion.—A negatively charged ion. An example is the chloride ion in a solution of sodium chloride. In sodium sulfate, the sulfate ion, a combination of sulfur and oxygen, is the anion. (See ion and cation.)

Atmosphere.—A unit for measuring osmotic pressure (osmotic concentration) or the water absorbing or retaining forces of a solution containing dissolved material. It is usually determined indirectly by measuring the number of degrees below zero centigrade that such a solution will freeze.

Base.—Caustic alkalies, lime, ammonia, and other chemical groups that unite with acids to form salts are bases. With reference to exchangeable or adsorbed bases, the elements sodium, potassium, calcium, and magnesium are considered bases rather than the oxides or hydroxides of these metals.

Cation.—A positively charged ion. An example is the sodium ion in a solution of sodium chloride. (See ion and anion.)

Desalinization.—Removal of salts from soil, usually by leaching.

Equivalents per million (e. p. m.).—This unit has recently been adopted by water analysts as being more desirable than milliequivalents per liter (m. e./l.). Technically the water is measured on a weight rather than a volume basis. In water, 1,000,000 milligrams is approximately 1 liter, and the units e. p. m. and m. e./l. are numerically almost equal. When dealing with waters of high salt content in which the specific gravity is greater than 1, there will be a slight correction when converting one unit to the other. (See milliequivalents per liter.)

Conversion Factors

Cations	*Equivalent weight*	*Anions*	*Equivalent weight*
Calcium (Ca)	20	Carbonate (CO_3)	30
Magnesium (Mg)	12.2	Bicarbonate (HCO_3)	61
Sodium (Na)	23	Sulfate (SO_4)	48
Potassium (K)	39.1	Chloride (Cl)	35.5
		Nitrate (NO_3)	62

To convert to parts per million (p. p. m.), multiply concentrations in equivalents per million (e. p. m.) by the equivalent weight of the ion. Conversely, to convert to equivalents per million, divide the parts per million by the equivalent weight of the ion.

Hydrogen-ion concentration (pH).—A logarithmic scale of the reciprocal of the hydrogen-ion concentration of 0 to 14, used to measure the acidity or alkalinity of a substance. Precise neutrality is pH 7.0. If the soil contains alkali (black alkali) the pH value will be above 8.5 and may exceed 10.0. Acid soils have pH values below 7.0.

Ion.—An electrically charged element or group of elements in a solution. Positively charged ions are termed cations; negatively charged ions, anions. (See anion and cation.)

Milligram equivalent (m. e.), *or milliequivalent per liter* (m. e./l.).—This unit is used to a large extent in water analyses. Chemical elements combine with each other in definite weight ratios. Thus 23 grams sodium ion will combine with 35.5 grams chloride ion, or 1 sodium ion will combine with 1 chloride ion to form sodium chloride, written chemically NaCl. An equivalent of sodium is therefore 23 grams, which will combine with its chemical equivalent of chloride ion, sulfate, or other substance. A milligram equivalent (m. e.) is 0.001 of an equivalent, or 0.023 gram of sodium or 0.0355 gram of chloride. The m. e. per liter of sodium is therefore 0.023 gram of sodium in a liter of water.

Miner's inch.—This is a unit for the measurement of flow of irrigation water, the value of which varies from State to State. In Arizona, Montana, and Oregon it is $\frac{1}{40}$ cubic foot per second. In Idaho, Kansas, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, and Utah it is $\frac{1}{50}$ cubic foot per second. In Colorado it is $\frac{1}{38.4}$ cubic foot per second. In California the statute miner's inch is $\frac{1}{40}$ cubic foot per second, but by custom in southern California it is $\frac{1}{50}$ cubic foot per second.

Osmotic concentration, osmotic value, and osmotic pressure.—A sugar or a salt solution can be placed in a semipermeable bladder of material that will allow water to pass through it and hold the sugar or salt. When immersed the bladder will soon distend because water will enter it. The pressure exerted is proportional to the quantity of solute (sugar or salt in this case) and is called osmotic pressure, because it arises by reason of the water passing through the membrane. A solution is said to have an osmotic pressure even though it is not confined, referring to the osmotic pressure it would have if suitably confined.

The terms "osmotic concentration" and "osmotic value" are widely used somewhat synonymously to mean the concentration of salts that will produce a certain osmotic pressure. The unit of expressing these forces for plant work is the atmosphere, approximately 15 pounds to the square inch. Actually the measurements are rarely made by confining the solution in a semipermeable membrane, but instead, the freezing-point depression of the solution is measured and these values are converted to atmospheres by proper formulas.

The importance of this measurement lies in the fact that salinity is to a large extent a form of physiological drought, in which the plant has difficulty in obtaining water. The osmotic concentration of a solution measures this water-retaining force. Further, greenhouse tests have shown that the best correlation between plant growth and salt concentration is obtained when the concentration of salts is expressed in atmospheres. When this unit is used, differences between salts may largely disappear. The approximate relation between the various units for measuring salt concentration in atmospheres is shown in table 4.

TABLE 4.—*Equivalent concentration*[1] *of salts expressed in atmospheres*

Items of comparison	Osmotic concentration (atmospheres)			
	1	2	4	6
Parts per million (p. p. m.):	*Units*	*Units*	*Units*	*Units*
Calcium chloride ($CaCl_2$)	1,840	3,720	7,600	11,500
Magnesium chloride ($MgCl_2$)	1,560	3,150	6,390	9,640
Sodium chloride (NaCl)	1,360	2,760	5,620	8,480
Magnesium sulfate ($MgSO_4$)	3,970	8,610	18,700	29,300
Sodium sulfate (Na_2SO_4)	2,400	4,970	10,580	16,500
Sodium bicarbonate ($NaHCO_3$)	1,790	3,700	7,640	11,800
Specific electrical conductance ($K \times 10^5$ at 25° C.):				
Calcium chloride	364	706	1,350	1,950
Magnesium chloride	354	690	1,310	1,900
Sodium chloride	266	520	1,020	1,520
Magnesium sulfate	415	760	1,400	1,980
Sodium sulfate	337	650	1,260	1,860
Sodium bicarbonate	180	358	700	1,030
Milliequivalents per liter (m. e./l.) or equivalents per million (e. p. m.):				
Calcium chloride	33	67	137	207
Magnesium chloride	33	66	134	202
Sodium chloride	23	47	96	145
Magnesium sulfate	66	143	310	486
Sodium sulfate	34	70	149	232
Sodium bicarbonate	21	44	91	140

[1] Calculated from data taken from International Critical Tables (*20*).

The value of conductance per atmosphere varies with the composition of the solution. It will be noted from table 4 that it takes more units of magnesium salts to produce 1 atmosphere of osmotic concentration than it does of sodium salts. Calcium salts fall between sodium and magnesium salts. The ratio of conductance to parts per million varies from about 5 to 10, depending on the nature of the salts present, with an average value for waters in general of about 7.

Parts per million (p. p. m.).—The concentration of salt, or of a single salt or salt constituent in water, is often expressed in parts per million. It refers to the number of parts by weight of this constituent in 1,000,000 parts by weight of water.

Percent salt.—This is the quantity of salt expressed as a percentage of the dry weight of the soil. An acre of soil to a depth of 1 foot, 43,560 cubic feet, will weigh about 4,000,000 pounds; 1 percent of salt in the soil would therefore be

about 40,000 pounds, or 20 tons in an acre-foot. On the percentage basis Kearney and Scofield (*12*) have classed soils as follows:

Salinity:	*Percent salt*
Weak	0.1 to 0.4
Medium	.4 to .6
Medium strong	.6 to .8
Strong	.8 to 1.0

The unit "percent" is not used frequently for water, but, when used, it refers to the number of parts by weight of salt in 100 parts by weight of water.

Saline soil.—A soil not excessively alkaline that contains an excess of soluble salts (more than 0.2 percent) and has a pH value less than 8.5.

Salt.—The product, other than water, of the reaction of a base with an acid.

Soil solution.—The moisture bathing the soil particles and containing dissolved minerals, air, and other material is called the soil solution.

Specific electrical conductance ($K \times 10^5$ at 25° C.).—This unit measures the conductance of a water or soil to electricity. Addition of salt to the water or soil water increases its conductance. The specific conductance (K) of a salt used for chemical work has been multiplied by 10^5 (100,000), so as to avoid the use of decimal values for soils work. This unit is an excellent and rapidly determined value for obtaining an index of the total salt content of a water, as all cations and anions carry current. The conductance of a soil solution is a good index of the effect of such a soil solution on plant growth.

Constants and Conversion Factors

1 acre=43,560 square feet.
1 acre-foot soil weighs 4,000,000 pounds (approximate).
1 acre-foot water weighs 2,720,000 pounds (approximate).
1 cubic foot a second (c. f. s.)=
  50 miner's inches in—
    Idaho, Kansas, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Utah, and southern California.
  40 miner's inches in—
    Arizona, California (statute), Montana, and Oregon.
  38.4 miner's inches in Colorado.
1 c. f. s. for 24 hours=1.98 acre-feet.
Gallons per minute (g. p. m.) $\times$ 0.002228=c. f. s.
1 U. S. gallon=
  231 cubic inches,
  8.345 pounds, or
  0.1337 cubic foot of water.
  58,417 grains.
1 cubic foot=
  7.4805 gallons water at 59° F., or
  62.374 pounds.
1 cubic foot of soil in place weighs 70 to 105 pounds.
Soil particles, specific gravity=2.65.
Grains per U. S. gallon $\times$ 17.1=parts per million (p. p. m.).
P. p. m. $\times$ 0.00136=tons per acre-foot.

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